A NEW TOOL STEEL for HOT FORMING GEARS

By Ed Tarney
Hot forming operations like forging, extrusion, hot upsetting, piercing, and any other operations involving deformation of solid hot metal place difficult demands on tool steels. The operating environment is above about 600°F (320°C), and may often exceed the heat treating temperatures of traditional tool steels. Tools and dies may typically be required to run at or above temperatures of 800/1200°F (425/650°C).

The temperatures involved limit the steels that are suitable for use. Tool steels used for hot forming tools require a combination of high-temperature strength (hot hardness and temper resistance), wear resistance, and toughness. In applications involving thermal cycling (intermittent cooling, etc.), heat check resistance is also required. A special category of hot work tool steels exists specifically for these applications.

Traditionally, H13 is the most common heat treatable tool steel used for these tools. It offers reasonable high temperature strength and toughness, but not high hardness or wear resistance. It generally performs best where thermal shock resistance and breakage resistance are needed. Over the years, other hot work steels in the same family have been developed, usually to try to gain increased hardness or wear properties. Such steels have included H14, H19, H21, and similar grades. Most of these other higher alloy hot work die steels have found limited acceptance at best. Common reasons may be that they offered only a limited improvement over the properties of H13, or performed only in specialized applications, or because the higher alloy content necessary to provide enhanced wear or hardness properties caused reduced toughness, and created too much risk of breakage. In effect, the closer these steels came to emulating high speed steels, the more they acquired some of the inherent liabilities of high speed steels, primarily poor breakage resistance (low toughness). Most of these toughness limitations are due to high alloy content, segregation, and high carbon content. Despite their higher hardness and wear resistance, as well as better temper resistance, high speed steels such as M2 are usually considered too brittle to be reliable for forging dies. Thus, the need for a high hardness, wear resistant die steel for hot forming has gone largely unanswered.
A new tool steel has been developed, combining the high hardness and temper resistance of high speed steels, along with the toughness of hot work tool steels. The toughness has been maintained by the use of a powder metallurgy (CPM) manufacturing process to eliminate segregation. This steel allows forging and hot forming producers the opportunity to use tooling with significantly higher hardness and longer wear life than offered by traditional hot work steels.

The CPM manufacturing process has been used for more than 30 years in the production of high speed steels and cold work tool steels, such as used for cutting tools, as well as punches, dies, and other metal-forming tools. One key performance benefit of such steels is the improved toughness obtained from the CPM process.

Another benefit is the ability to produce higher alloy content steels to offer enhanced wear properties compared to traditional cold work steels (such as A2 or D2). This same process is now being used to produce CPM 1V, a new die steel specifically intended for use in hot forming operations.

The chemical analysis of 1V is designed to mimic the analysis of M2 high speed steel, without the carbide content. That is, the matrix of 1V offers similar temper resistance (resistance to softening when exposed to elevated temperature) to the matrix of M2. Without the carbides, the wear properties are lower than M2, although they are better than...
The properties of 1V are designed to offer a combination of toughness and wear properties suitable for long-running dies, or dies in high wear applications. Figure 2 compares the properties of 1V against some other common tool steels. It is apparent that 1V offers wear properties far exceeding the traditional hot work steels such as H13, and even some cold work die steels, such as A2 or S7, exceeded in this group only by the high speed steel M2. Simultaneously, the toughness far exceeds that of cold work grades and high speed steels, and even some high alloy hot work steels. The toughness of 1V is comparable to the standard H13, especially when compared to H13 at high hardness (~50 HRC), even when heat treated to be significantly higher hardness (up to 54-58 HRC). The higher hardness may be of particular benefit when high forging or forming pressures cause deformation in H13 at lower hardnesses. This combination gives 1V the possibility to outperform H13 safely and reliably in demanding forging applications.

The chemistry of 1V is based on the matrix of high speed steels. Thus, 1V offers attainable hardness, tempering resistance, and hot hardness similar to high speed steels. Figure 3 shows the tempering resistance of 1V, compared to a number of other hot work tool steels. This affords two advantages for 1V. First, the higher attainable hardness provides higher room temperature deformation resistance and wear properties than H13. Second, being able to retain its room temperature hardness advantage over H13 during exposure to higher...
temperatures allows 1V to multiply its advantages over H13, to encompass heat exposures beyond H13’s capacity.

**Applications and Operating Experience**

Typical applications for 1V include all manner of hot or warm work tooling, including forging dies, especially smaller dies, hot header dies, hot shear dies, punches, and extrusion dies. Some field trial performance results are described below.

In a gear forging die for transmission parts and CV joint parts (Figure 4), the high hardness of 1V allows the gear tooth areas to be produced to tighter tolerances than with other lower hardness die steels. Teeth are forged directly to final net shape, with no gear cutting performed after forging. In addition, it is easier to hob the die impression into the CPM 1V tool than other conventional die steels.

1V is used to forge control arm ends at a major automotive supplier. The die makes the cup section (bushing) of the control arm. 1V has more than doubled the die performance of H-13.

In a hot forging punch, piercing a hole through an alloy steel wrench blank at 2200°F (1200°C), 1V punches last about 75 percent longer than H19 (1400/1500 parts, vs. 800/900 parts.)

In a hot shear blade, cutting stainless steel feedstock in a forging plant, 1V is being used to replace H19 and modified high carbon H13 for shearing hot stainless steel bar in mechanical and hydraulic shears. Depending on the previous grade and application, the 1V shear blades last two to six times longer than the previous blades.

In related applications to the gear forming industry, CPM 1V has found good use in service for cold forming tools such as roll form racks and rolling dies. In these tools, the teeth of the tools are loaded cyclically in compression as they are forming the work material. A common failure mode in such tools is fatigue cracks near the base of the teeth from the constant application and release of compressive stress. The fatigue is similar to a common bearing component failure called rolling contact fatigue, from a similar situation in roller bearing where a spot in a bearing component is loaded cyclically in compression.

Conventional tools are typically made from M2 or similar grades. For such applications, where the operation is performed at room temperature, the red hardness (tempering resistance) of a high speed steel is not necessary. In addition, since fatigue is a common failure mode—rather than wear—the high carbide volume of M2, which contributes to wear resistance, is also of limited benefit.

Traditionally, the fatigue strength of a material is related to both the yield strength and the ductility or toughness. The CPM 1V offers the capability of achieving the strength of high speed steel, thus offering the required high yield strength. In addition, the inherent uniformity of the CPM microstructure enhances ductility and improves resistance to crack formation and propagation by eliminating the carbide segregation characteristic of conventional high speed steel. Also, the low carbide volume of
the 1V chemistry limits the total volume of carbides present, further improving the toughness. Thus, 1V offers the matrix properties of high speed steel which are of most benefit for these applications, without the limitations of the higher carbide volume.

A side benefit of the CPM process is the predictability of dimensional changes in heat treat for long, thin tools such as rolling racks, thus offering tool makers the benefit of consistent expectation for finishing operations.

Recommendations

The unique chemistry of 1V, combined with the CPM manufacturing process, has resulted in a grade with previously difficult to combine properties. 1V offers a combination of excellent toughness, high attainable hardness, and retention of hardness at high temperature.

These properties allow 1V to successfully combine the desirable attributes of hot work tool steels and high speed steels, making high hardness capability available for warm or hot forming tools. Hardnesses in the mid to high 50s HRC are easily achieved and successfully used, contributing to longer-wearing dies. CPM 1V can extend the operating up-time for any hot work tool where longer wear life is needed. 1V also offers benefits for high strength tools requiring fatigue resistance, where the wear properties of high speed steels are secondary. High hardness can be combined with high toughness, in applications where cracking, rather than abrasion, are common failure modes.

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Ed Tarney is chief product metallurgist, tool steels, for Crucible, which is located in Syracuse, New York. CPM tool steels—including 1V, as well as the CPM Rex high speed steels and the CPM “Killer V” cold work steels, are manufactured by Crucible. They are available directly from Crucible Service Centers across North America, and around the world through international partners. For more information send e-mail to techservices@crucible.com or call (800) 365-1185. The company’s Web site is [www.crucible.com].

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